Title:

Fractional PM Collection Efficiencies of Residential and Commercial Air Cleaning Units

Extended Abstract #49

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INTRODUCTION

Airborne particles in buildings, whether due to intentional dissemination or natural occurrence, can have very serious impacts on the health of the occupants. Many organizations have issued guidance documents regarding methods for reducing airborne particle concentration. In particular, information on the performance of commercially available air cleaning devices is not readily available and generally is limited to the removal efficiency in the 0.3 to 10 μm particle size range. Since some materials known to be hazardous to human health are smaller than 0.3 μm, information on the performance of air cleaning devices for the removal of nanoparticles is also needed.

To provide some practical information for building air quality methodology design, the U.S. EPA's Office of Research and Development (ORD) contracted with Battelle to evaluate the performance of a wide range of commonly used ventilation filters and whole-house in-duct electrostatic air cleaners (EACs). The air cleaners varied in MERV ratings from 6 to 16+ and spanned the entire range from flat-panel residential furnace filters to deep-pleated, rigid-cell high efficiency units. A total of 27 different filters/EACs were evaluated.

In accordance with the ASHRAE 52.2 test methodology, all of the air-cleaning units were evaluated for filtration efficiencies over the 0.3 to 10 μm range using an optical particle counter. Building upon past efforts[1,2], a scanning mobility particle sizer (SMPS) was used to determine the filter efficiencies down to 0.03 μm. The residential filters were tested at the typical flow rate of approximately 295 feet per minute (fpm), while the commercial filters were tested at approximately 492 fpm. Tests were performed with both "off-the-shelf" units and units aged in a typical or simulated use environment. Testing was also performed against a bioaerosol challenge to demonstrate the similarity in performance between inert and biological particles.

Empirical equations were developed based on the data acquired during the evaluations of the "off-the-shelf" filters relating particle collection efficiency to particle physical diameter over the range of 0.03 to 10 μm. One equation was fit to represent all of the filters with a given MERV rating. These equations provide an empirically validated prediction for the performance of a filter for a given MERV rating for use in the design of a particulate removal system and/or incorporation into indoor air quality models.

Experimental Methods

A total of 24 filters and 3 EACs were evaluated. All of the tested units were commercially available throughout the U.S. Selection of the tested units was based on known information with regard to the market share possessed by various manufacturers, with an emphasis on commercial filters over residential filters, and emphasizing filters with higher efficiencies (MERV ratings greater than 10). Only duct-mounted electronic air cleaners were included in the study.

For all of the cleaners, inert aerosol evaluations were performed to measure their collection efficiency "off-the-shelf" for particles with diameters between 0.03 and 10 μm. The pressure drops of the units were also evaluated at 50, 75, 100, and 125% of the maximum flow rates that the units would likely encounter in actual use. All testing was performed in accordance with ANSI/ASHRAE Standard 52.2-1999[3] by Intertek ETL Semko in their certified ASHRAE 52.2-1999 test facility in Cortland, New York.

Two particle sizing and counting instruments were used for the inert aerosol tests: a Climet model 500 Optical Particle Counter (OPC) covering the particle diameter size range from 0.3 to 10 μm, and a TSI Scanning Mobility Particle Sizer™ (SMPS) covering the range from 0.03 to 0.3 μm. The OPC uses a laser-light illumination source and has a wide collection angle for sensing the scattered light. The SMPS consisted of a TSI Model 3080L electrostatic classifier and a TSI Model 3022A-S condensation particle counter. The two selected instruments measure particles based upon different physical properties: electrical mobility in the case of the SMPS and light scattering in the case of the OPC. This did not affect the efficiency measurements for specific particle sizes, but it did result in occasional minor discontinuities between the filtration efficiency curves obtained from the two instruments.

An external air atomizing nozzle was used along with a KCl solution of approximately 300 g KCl to 1 liter of distilled water to generate aerosol, for the 0.03 to 10 μm tests. For the 0.03 to 0.3 μm tests, a Collison nebulizer was utilized with a solution of approximately 100 g KCl to 1 liter of distilled water. Both generators were connected to a 12 inch (0.30 m) diameter, 51 inch (1.3 m) tall transparent acrylic spray tower. The tower allowed the salt particles to dry as well as allowing larger particles to settle out of the challenge aerosol air stream. After drying in the spray tower, the challenge aerosol passed through an aerosol neutralizer before being injected counter to the airflow in the test duct.

As specified in ANSI/ASHRAE Standard 52.2-1999[3], the computation of inert aerosol filtration efficiency was based on the ratio of the downstream-to-upstream particle concentrations corrected on a channel-by-channel basis for the following:

- Background counts (i.e., upstream and downstream counts observed when the aerosol generator is off) and
- The correlation ratio measured at the start of the test sequence.

It should be noted that these tests did not include the ASHRAE 52.2-1999[3]) dust loading procedures. Only the initial collection efficiency and pressure drop tests were performed.

Results

Figures 1 and 2 graphically illustrate representative samples of the collection efficiencies that were measured for "off-the-shelf" MERV 12 and MERV 14 filters, respectively. As shown in Figures 1 and 2, the collection efficiencies measured with the OPC (0.3 to 10 µm) generally corresponded very well with the collection efficiencies measured with the SMPS (0.03 to 0.3 µm), in the common region of overlap around 0.3 µm with only a few discontinuities. The most penetrating particle size was consistently in the 0.1 to 0.3 µm range. As shown in Figure 1, the MERV 12 filter performances were very similar in the 1 to 10 µm region, but they varied considerably for submicron particles. The MERV 14 filter performances were very similar over the 0.3 to 10 µm region, but they also varied somewhat in the 0.03 to 0.3 µm region.

Figure 1: Results and Curve Fit from the "Off-the-Shelf" MERV 12 Filter Tests

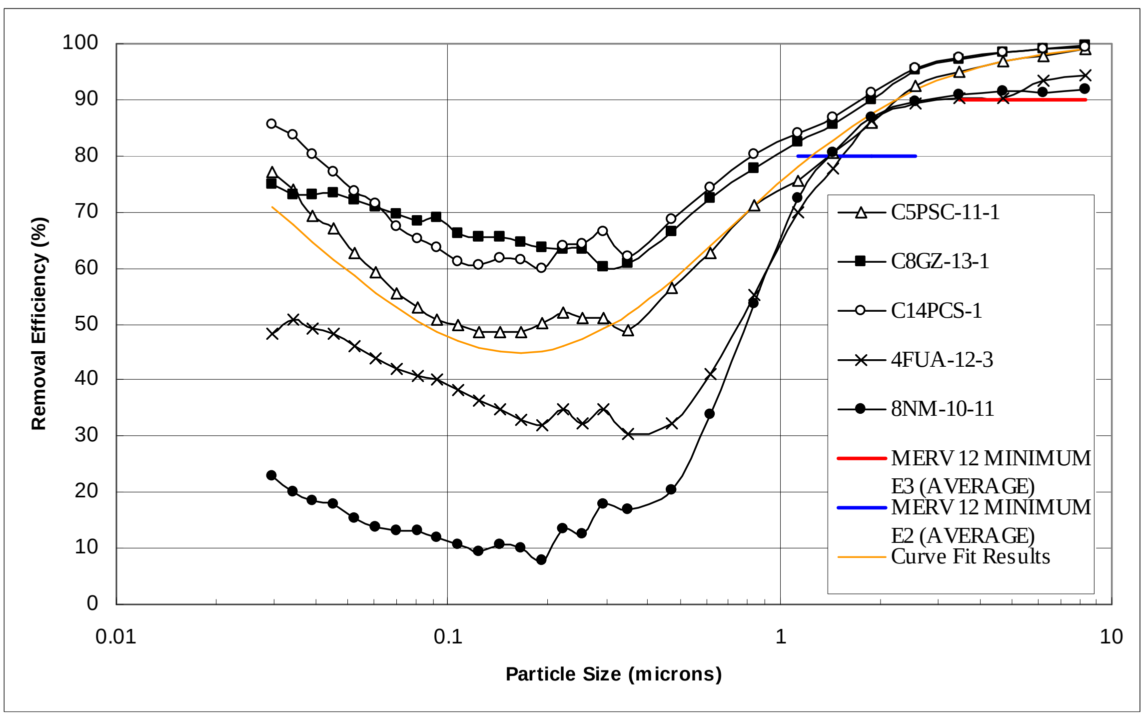
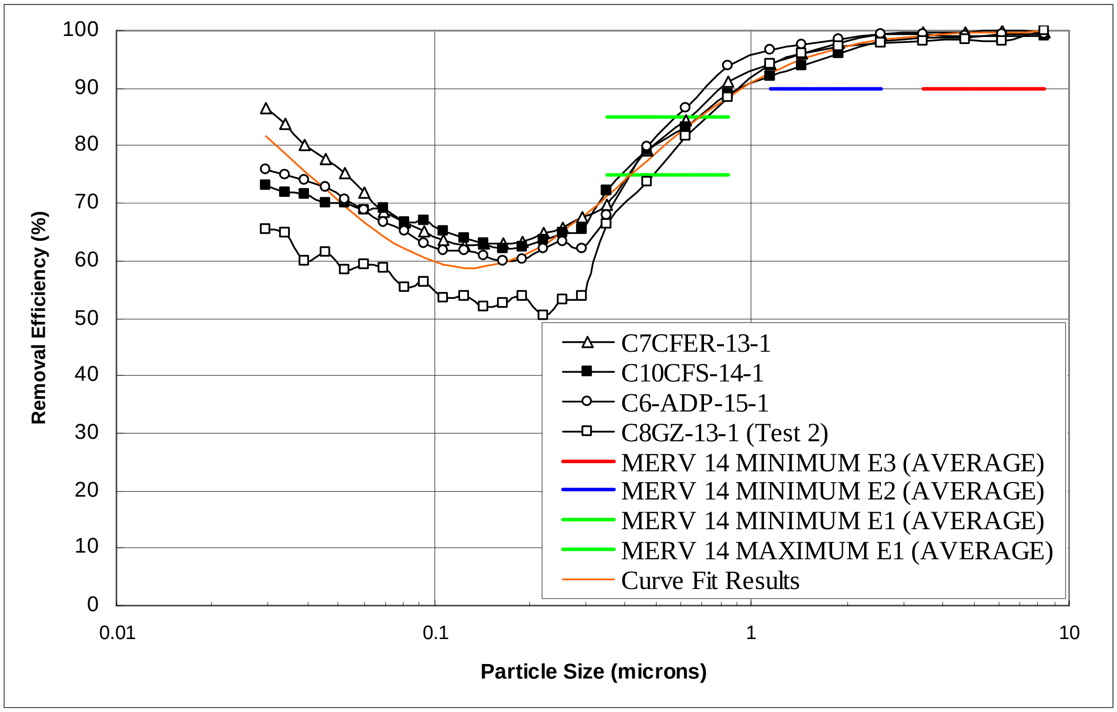


Figure 2: Results and Curve Fit from the “Off-the-Shelf” MERV 14 Filter Tests



Empirical equations were developed relating the measured particle collection efficiency to particle physical diameter over the range of 0.03 to 10 µm. These equations were developed only for un-aged, unconditioned filters, and one curve was fit to all of the filters whose test results resulted in a given MERV rating (as shown in Figure 1). The curves were fit using TableCurve 2D® software (SYSTAT Software Inc.). To generate the curves, all of the experimental collection efficiency data was combined by averaging the penetrations and weighting the mean values proportionally to the inverse of the standard deviation of the values. A third order polynomial was fit between the log of the percent penetration and the log of the particle diameter. The curve fits provide an empirically validated prediction for the performance of a filter that performs at a given MERV rating, not a prediction for a particular make and model of filter.

Summary

Table 1 provides a summary of the results from the inert aerosol evaluations of unconditioned, un-aged (“off-the-shelf”) filters. As shown in Table 1, the pressure drops of the filters between MERV 5 and 10 at 370 fpm did not appear to be substantially different, with a good deal of overlap between the average pressure drops. However, there was a significant increase in pressure drops between the MERV 10 and MERV 12 filters, between the MERV 14 and MERV 16 filters, and between the MERV 16 filters and the HEPA filter. As expected, the collection efficiency of the filters generally increased with MERV rating. Therefore, consumers of air filters will need to balance the higher pressure drop and cost of MERV 12 to MERV 16 filters with the expected increase in performance.

Table 1. Summary of the Results from the Inert Aerosol Evaluations and Curve Fits of Un-aged Unconditioned Air Cleaners.

MERV Rating	Number of Filters Tested	Average Pressure Drop (in. of water) at 370 fpm	Predicted Removal Efficiencies (%) from Curve Fits					
			0.03 µm	0.1 µm	0.3 µm	1.1 µm	3.5 µm	8.4 µm
5	1	0.24	13	0	5	24	34	34
6	2	0.22 $\pm$ 0.06	12	6	5	16	35	53
7	6	0.30 $\pm$ 0.08	44	13	20	47	61	65
8	4	0.26 $\pm$ 0.03	40	20	22	52	75	86
10	1	0.29	55	37	29	53	85	97
12	5	0.46 $\pm$ 0.09	71	47	49	78	95	99
14	4	0.48 $\pm$ 0.11	82	59	68	93	99	99
14-15 (EACs)	3	0.14 $\pm$ 0.03	94	87	87	93	97	98
16	3	0.73 $\pm$ 0.15	99	95	96	99	99	99
16+ (HEPA)	1	0.97	>99	>99	>99	>99	>99	>99

Table 2 lists the results from the curve fits to the collection efficiencies that were measured for the “off-the-shelf” filters. As shown in Table 2, all but one of the curve fits possessed correlation coefficients (r^2) greater than 0.89, indicating an excellent representation of the data. The MERV 6 curve fit possessed a lower correlation value (0.83) but matched the data well. These curve fits provide a valuable tool that will enable consumers to accurately estimate the collection efficiency of a filter with a given MERV rating to determine if its likely performance will justify its increased cost and pressure drop.

Table 2. Summary of the Results from the Curve Fits to the Inert Aerosol Evaluations of Un-aged Unconditioned Air Cleaners.

MERV Rating	Equation [(a)]	Parameters		Correlation Coefficient (r^2)
5	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 1.8906 c = 0.0307	b = -0.1722 d = 0.0793	0.8935
6	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 1.9311 c = -0.1243	b = -0.1441 d = -0.0234	0.8332
7	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 1.7467 c = -0.0036	b = -0.3314 d = 0.1381	0.9064
8	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 0.5839 c = 0.1289	b = 0.1675 d = 0.0188	0.9658
10	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 1.7083 c = -0.6721	b = -0.5759 d = -0.1775	0.9852
12	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 1.3943 c = -0.6240	b = -0.9080 d = -0.0404	0.9902
14	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 0.9531 c = -0.8443	b = -1.4941 d = -0.0013	0.9668

14 and 15 (EACs)	$Y = a + bx + cx^2 + dx^3$ where Y = log of percent penetration	a = 0.8422 c = -0.2157	b = -0.6469 d = 0.1645	0.9600
16	$\ln Y = a + bx + cx^2 + dx^3$ where Y = percent penetration	a = 0.3855 c = 0.5326	b = -2.0698 d = 1.3895	0.9728
16+ (HEPA)	$Y = a + bx + cx^2 + dx^3 + ex^4$ where Y = percent penetration	a = 0.0361 c = 0.5119 e = -0.1816	b = -0.3506 d = 0.0481	0.8917

[a] x = log of particle diameter

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